Transformation of a combustion vehicle to electric

Transformación de un vehículo de combustión a eléctrico

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Abstract

Colombia, like other developing countries, has been incorporating various electric vehicles in its automotive park, motivated by an emerging policy of incentives, a concern for the environment and health, and a high cost of fuel; however, these types of vehicles remain relatively expensive. The transformation of thermal vehicles (combustion engine) to electric vehicles becomes an interesting option, due to its low cost compared to new commercial electric vehicles and the positive environmental

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impact which represents. The present work illustrates the technological steps that have been required in the transformation from a traditional internal combustion vehicle to an electric one (sprint vehicle), showing the economic benefit and the impact on the attenuation of greenhouse gases. The analysis of the traction dynamics and validation with various laboratory and field (road) tests, have shown the viability of a transformed vehicle, which satisfies the power demands under different load conditions, typical of high slopes on Latin American roads. A synthesis of the experience has been published in https://www.youtube.com/watch?v=a7DY8p7J1_Q&feature=youtu.be.

Keywords: electric vehicles, contamination, sustainable mobility.

Resumen

Colombia, al igual que otros países en desarrollo, viene incorporando en su parque automotor diversos vehículos eléctricos, motivado por una emergente política de incentivos, una preocupación por el medio ambiente y la salud y un alto costo del combustible; sin embargo, este tipo de vehículos continúa siendo relativamente costosos. La transformación de vehículos térmicos (motor de combustión) a vehículos eléctricos se convierte en una opción interesante, debido a su bajo costo comparado con los vehículos eléctricos comerciales nuevos y el impacto ambiental positivo que representa. El presente trabajo ilustra las etapas tecnológicas que se han requerido en la transformación de un vehículo tradicional de combustión interna a eléctrico (vehículo sprint), mostrando el beneficio económico y el impacto en la atenuación de gases de efecto invernadero. El análisis de la dinámica de tracción y validación con diversas pruebas de laboratorio y de campo (carretera), han mostrado la viabilidad que posee un vehículo transformado, que satisface las demandas de potencia bajo diferentes condiciones de carga, propias de las elevadas pendientes que se encuentran en las carreteras latinoamericanas.

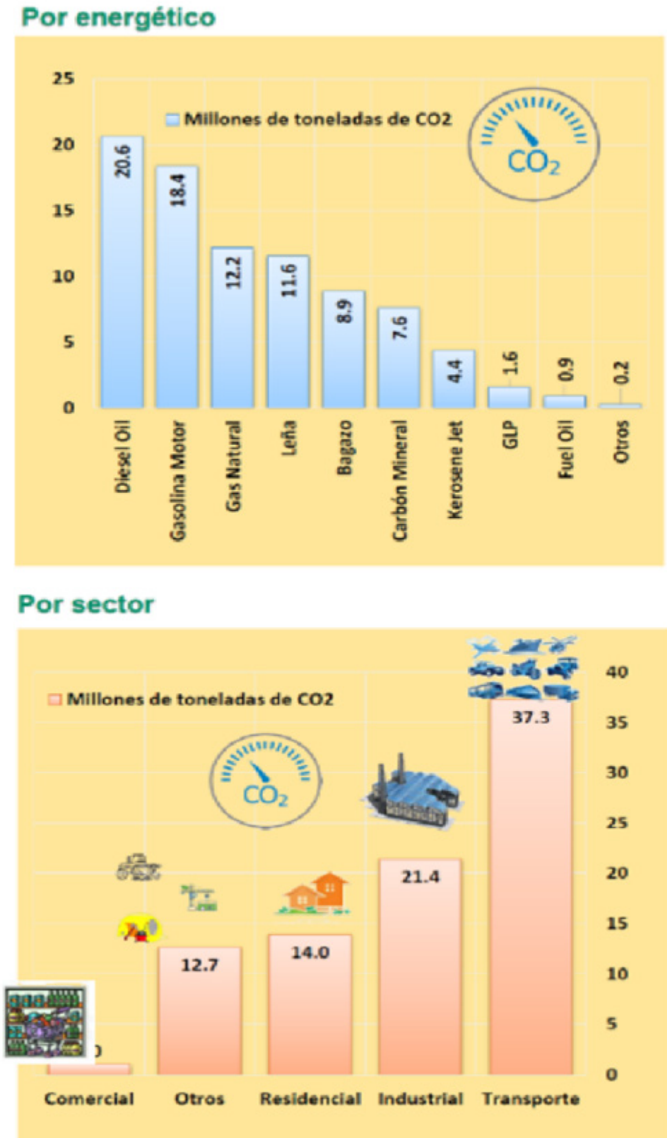
Una síntesis de la experiencia ha sido publicada en https://www.youtube.com/watch?v=a7DY8p7J1_Q&feature=youtu.be.

Palabras Clave: vehículos eléctricos; contaminación; movilidad sostenible.

1. Introduction

Traditional transportation (based on combustion) has had, in recent years, an increasingly harmful effect on the environment and human health. Recently, a study published by the Lancet commission (Landrigan, 2018) states "For decades, pollution and its harmful effects on people's health, the environment, and the planet have been neglected both by Governments and the international development agenda. Yet, pollution is the largest environmental cause of disease and death in the world today, responsible for an estimated 9 million premature deaths". Nine million represent 16% of all premature deaths in the world today. Furthermore, the costs due to pollution represent 4.6 trillion dollars per year to the global economy, equivalent to 6.2% of global economic output. Transportation not only affects human health but is also the main source of greenhouse gases. Recent reports from the Mining and Energy Planning Unit UPME (2019) (Figure 1) show transportation as the sector of the economy with the highest CO2 emissions in the country with contributions of 37.3 million tons per year. On the other hand, transport becomes the main source of pollution components such as particulate matter (PM10) and Nitrogen Oxide. Other studies (Vidal, 2016) have shown how the growth of cities and therefore the number of vehicles and the industrial sector, have increased the problem of pollution and public health. The mandatory quarantine that humanity is currently experiencing due to the pandemic, has allowed us to appreciate the positive effects on the environment derived from the non-overcrowding of vehicles on the roads, allowing the enjoyment of a cleaner environment and the observation of mountains and snow-capped mountains. that were previously not perceived due to pollution.

Figure 1. *CO2 emissions by type of fuel and sector (UPME)*



Electric mobility therefore represents an interesting alternative to mitigate this problem, even more so when it involves saving costs for fuel, which is growing progressively in countries like Colombia. The transformation of combustion vehicles to electric vehicles has been implemented in various Latin American countries (Mexico, Peru, Ecuador and Venezuela), but generally they do not carry out a theoretical analysis and experimental tests that fully validate the performance of the transformed vehicle. There are studies that have made some interesting analyzes, such as Rodríguez (2015), which studies the behavior of various electric vehicles on the topology of Medellín; González (2010) describes the methodology used to convert a thermal vehicle to an electric vehicle without analyzing the behavior of the system. Other studies (Duque, et al., 2018) analyze different standardized ways to measure the autonomy of a vehicle, but do not incorporate the analysis of traction power. Other investigations (Asimakopoulos, 2010) analyze the conversion of a conventional vehicle to a hybrid, however, there are no studies that involve theoretical analysis and experimental tests for the full validation of the behavior of the traction dynamics and the electronic system of a transformed electric vehicle . In Latin America, electric vehicles still have a high cost for an end user, mainly influenced by the original factory price and the import costs involved. An example of this, the Nissan Leaf (24 kWh model) costs € 16,607 in Japan, € 29,460 in Spain, but in Colombia the cost amounts to € 34,300 (equivalent to $ 120,000,000 COP). Therefore, converting a vehicle with a combustion engine to an electric vehicle is an interesting and economically motivating option.

Materials and methods.

Below are the stages used in the vehicle conversion process.

2.1 Choosing of vehicle and traction dynamics analysis

After analyzing several alternatives, a Chevrolet Sprint vehicle (Suzuki Swift in the United States) was selected for the conversion, due to its low weight and its large space in the front cavity.

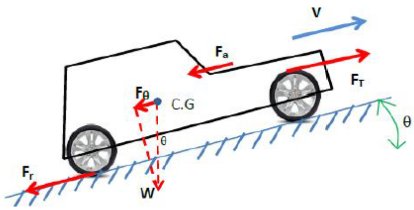
Figure 2. *Vehicle to transformation*

Technical characteristics: Tare: 675 kg
Power: 46.8 kW.
Weight/power ratio: 14.43. Displacement: 993 cm^3.

The vehicle's traction dynamics has been analyzed to establish the power requirements based on the different parameters, including the slope Θ (figure 3), normally high in Latin America. Equation (1) determines the power required for a vehicle involving the components slope FΘ, rolling Fr, aerodynamic effect Fa and acceleration [Jazar, 2016; Gillespie, 1992].

$$\dot{W} = \left[\underbrace{W\sin\theta}_{F\Theta} + \underbrace{C_r W\cos\theta}_{F_r} + \underbrace{\frac{1}{2}\rho S K_a V^2}_{F_a} + \underbrace{ma}_{acel}\right]V \qquad (1)$$

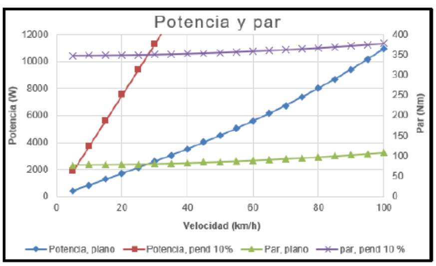
Figure 3. *Fuerzas restrictivas al movimiento de un vehículo*



W (weight), *Θ* (road slope), *Cr* (rolling coefficient), *ρ* (air density), *S* (vehicle cross section), *Ka* (drag coefficient), *m* (mass), *a* (acceleration), *V* (velocity).

Figure 4 shows the behavior of power as a function of vehicle speed.

Figure 4 . *Power and torque as a function of speed on flat terrain and 10% slope.*



Taken values:

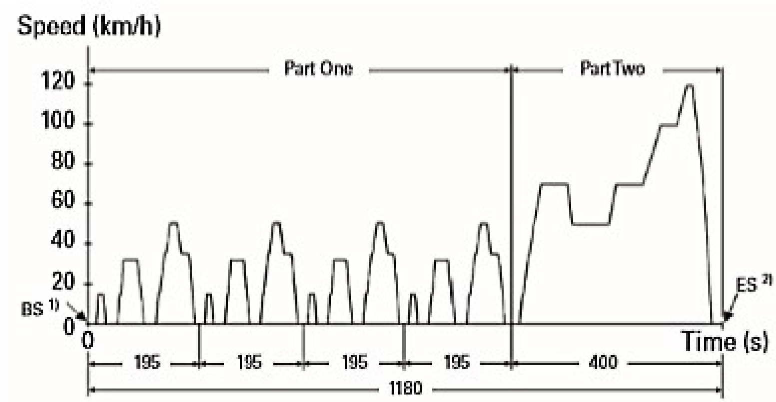
m = 1025 kg (675 vehicle + 5 passengers/70 kg) $Cr = 0.01$, ρ = 1.2 kg/m^3, $K_a = 0.2$, $a = 0$ (constant speed), $S = 1,3$ m^2, $\Theta = 0$ and 10% (flat terrain and high slope).

Speeds of 70 km/h are expected in favorable conditions (flat terrain). A 10 HP (7.5 kW) electric motor can satisfy these conditions (figure 4). However, with a slope of 10%, this engine will move the vehicle at 20 km/h. On Colombian highways (Latin America average) it is necessary to have a gearbox to deliver the required torque under demanding load conditions. As can be seen in figure 3, on a 10% slope the required torque amounts to 350 Nm. The characteristics of an electric motor do not allow to satisfy this level of torque, requiring a transmission box that amplifies the original torque of the motor.

2.2 Preliminary tests to combustion vehicle.

Combustion tests are important to determine how much pollution the vehicle emits into the atmosphere. For this, dynamic tests were developed based on the NEDC (New European driving Cycle) protocol (figure 5) to evaluate fuel consumption and polluting emissions. Measurements were taken of the vehicle on rollers (from the E20 dynamic test laboratory of the Technological University of Pereira).

Figure 5 . *Driving cycle: NEDC*

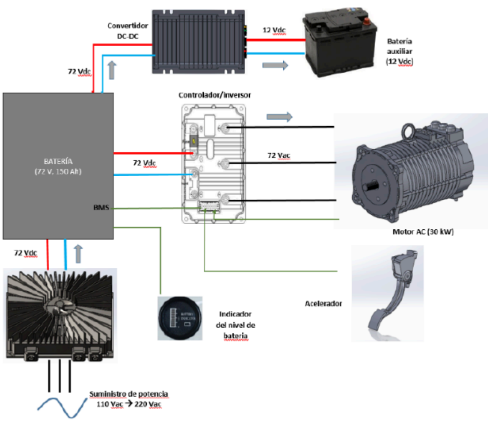


During testing, the average fuel consumption was 57.78 km/gallon (6.54 L/100 km). The combustion gases obtained were CO: 1.808 g/km, THC + NOx: 0.652 g/km. These values exceed the established international limits, which for this type of vehicle and according to the standards (Euro 4) are: CO: 1.0 g/km and HC + NOx: 0.3 g/km. In Colombia, vehicles are evaluated based on the Euro 2 protocol (resolution 910 of 2008), which establishes limits such as CO: 2.20 g/km and HC + NOx: 0.50 g/km. Taking into account the emission results, the selected vehicle is highly conducive to conversion.

2.3 Selection of the electrical kit.

The electric motor required according to the analysis of the traction dynamics (Figure 4) is 10 HP (7.5 kW). A motor of this capacity requires a 72 V electrical system. Figure 6 shows a basic connection diagram and the necessary components.

Figure 6. *General electrical connection diagram and required components*



- 72 V 400 A AC controller.
- DC-DC converter 12 Vdc - 72 Vdc
- CH4100 72 V 25 A charger.
- Electronic Throttle
- AC motor HPQ7.5YBE-72
- Vacuum pump for brake, 12 V.
- Lithium battery with casing and BMS (Battery Management System) control.

The main battery must be connected to the auxiliary 12 VDC battery (can be used from the original vehicle) through the DC/DC converters to charge it continuously, replacing the alternator function. The battery employs a BMS (Battery Management System) that requires to be connected to the controller to achieve feedback from the system. The electrical current demanded by the motor in the no-load tests registered peaks of 40 A (72 Vac) representing a consumption of 2880 W, with a motor rotation speed of 3000 RPM. The initial tests allowed to identify connectors, cables, necessary protections and range of work of the accelerator. Battery load tests were carried out by connecting to a 120 VAC electrical network (local network in Colombia), presenting consumptions of 14 A (1700 W).

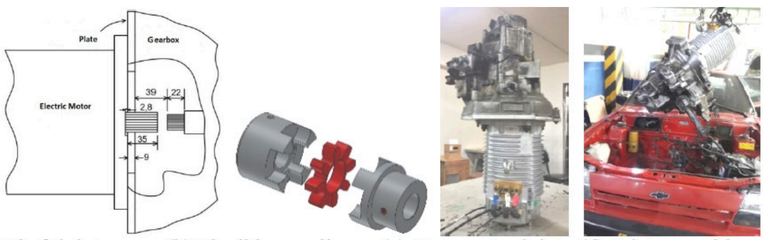
2.4 Replacement of the combustion engine.

The images in Figures 7 and 8 show different stages of the process.

Figure 7. *Stages of engine replacement*

On the left side you can see the combustion engine, which is removed together with the gearbox. This box is disassembled and coupled to the electric motor through a flexible coupling (preventing possible misalignments), to which grooved holes are made to firmly couple with the shafts of the box and the motor.

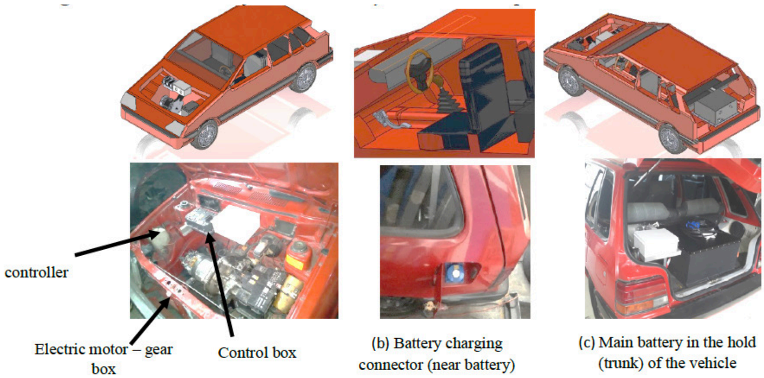
Figure 8. *Assembling and mounting of coupled electric motor and box*



(a) Shaft joint (b) Flexible coupling (c) Case-motor joint (d) Joint assembly

The box-engine assembly is coupled to the vehicle, using the supports of the original combustion engine. For the assembly projection, considering dimensions and optimization of the system, 3D modeling tools were used. The battery and charger are in the trunk of the vehicle, considering the dimensions and weights and the proximity of the charging connector, provided in the same place as the (original) fuel inlet. Figure 9 presents 3D projection and component location images.

Figure 9. *Design 3D and location of lithium battery and other components*



The control box (figure 9, left image) has been designed to implement overcurrent and voltage protections and incorporate a relay (or relay) to provide signal access to the system with activation of the vehicle's main switch signal. Figure 10 presents a diagram of the circuit used, keeping the location of components in the vehicle (top view).

2.5 Mass Balance

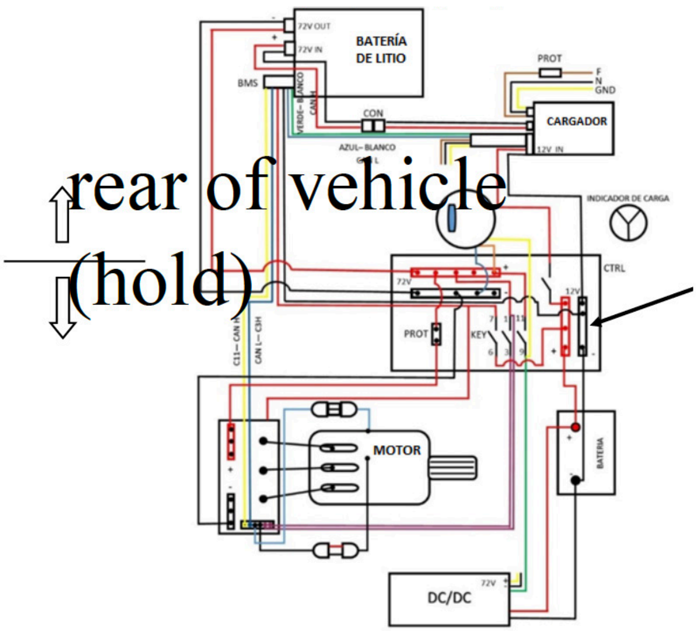
The total mass comparison of the vehicle was made before (combustion) and after transformation (electric). Weights of the different components were taken in each of the systems, Table 1 presents the results.

Table 1. *Component Weight Comparison*

Electric System		Combustion Motor	
Component	mass (kg)	Component	mass (kg)
Electric motor	40	Combustion motor	150
Lithium Battery	90	Combustible tank (full)	30
Controller	6	Radiator	5
Charger	5	Exhaust pipe	6
DC-DC Converter	1	Filters and pipes	5
Total	**142**	**Total**	**196**

The transformation of the vehicle into electric represents a weight reduction of around 30%, allowing the power demanded to be less for the same load conditions.

Figure 10. *Electrical Vehicle connection diagram (vehicle top view)*



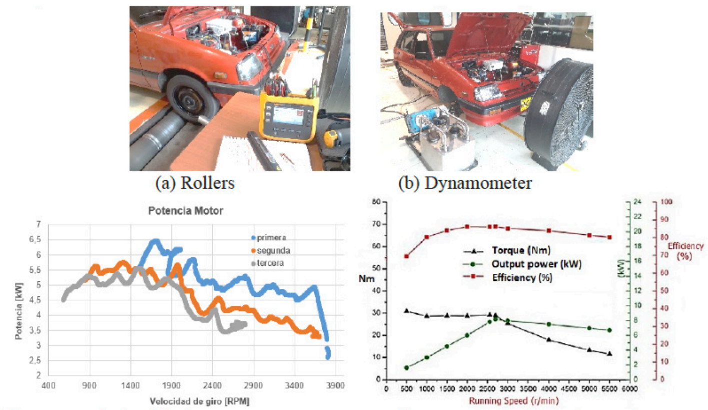
2.6 Experimental testes

At this stage, as a central contribution of this work, some results of tests of the system, carried out in the laboratory (dynamometer and roller) and in different road conditions will be presented.

2.6.1 Laboratory testes

Effective power measurement tests on the output shaft (traction) were carried out in the dynamic test laboratory of the Technological University of Pereira, using a cube dynamometer equipment (Dynapack). In the same way, autonomy tests were performed on rollers, following standard NEDC profiles (figure 5). Figure 11 presents images of the assembly and results.

Figure 11. *Roller and dynamometer mounting, power results and engine manufacturer curves*



(a) Rollers (b) Dynamometer

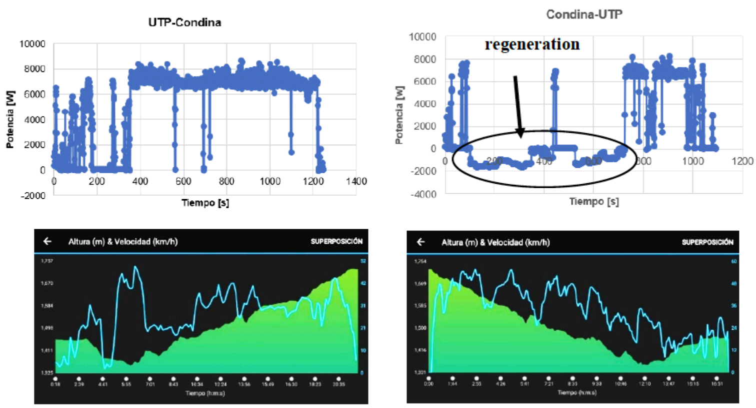
(c) Curves obtained in dynamometer (d) Motor curves (manufacturer)

The output powers were measured using the 1st, 2nd and 3rd gears with registers between 5 and 6.5 kW due to the loss represented by the transmission and efficiency of the engine itself. Comparing with the original engine manufacturer curves, a certain similarity in the behavior of the engine power is obtained, maintaining its value at low RPM and gradually falling after approximately 2000 RPM. The differences are presented by the power losses and dynamic variations, derived from the gearbox (the original motor curves are built with load analysis on the isolated motor, without transmission box). In rollers, following NEDC profiles), autonomy values (complete battery discharge) equivalent to 250 km were found. Comparing with a heat engine, a full tank (8 gallons) has a range of 320 km but with a cost of $ 72,000 higher than the cost of electricity demanded by the electric vehicle for the same journey, equivalent to $ 6000.

2.6.2 Road tests

Initially, preliminary tests were carried out with all passengers, on the road with short distances, to subject the system to real load conditions and validate the traction model and the performance of the regenerative brake. Figure 13 shows the typical curves generated in a path, in this case short path UTP-Condina-UTP (UTP: Technological University of Pereira).

Figure 12. *UTP-Condina-UTP road tests. Top: electrical power demand, bottom: altimetry curves (green) and speed (blue)*



(a) Ascent UTP-Condina (b) Decline, Condina-UTP

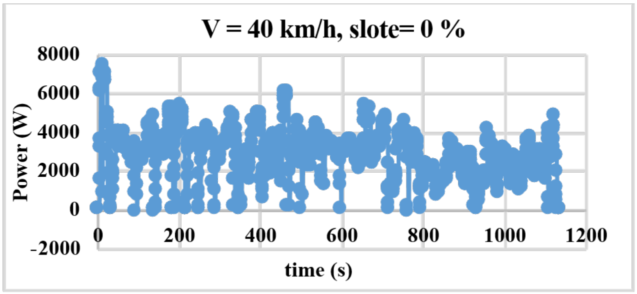
The average slope in the UTP-Condina ascent is 6%, the recorded energy consumed was 1858 Wh with a voltage reduction from 76.4 V to 75 V. It is to be noted, as is reasonable, that the highest speed in This route was presented on the descents, with very low power demands and, on the contrary, maximum powers are demanded on the ascents. In the Condina-UTP descent, the inertia reached was used to activate the regenerative brake, reaching powers in favor of 2 kW. The net demanded energy consumption recorded was 402 Wh with a voltage loss of only 0,5 V.

On the uphill, more demanding slope conditions place higher demands on power and torque, which roughly match the calculated traction dynamics. The nominal battery voltage is 72 Vdc, however, it can be charged up to 82 V (full load) and discharged up to 62 Vdc. This voltage reduction is generated with an energy discharge of 11 kWh. In ascent conditions, the vehicle traveled 9.89 km with an energy expenditure of 1,858 Wh, equivalent to 187 Wh/km. This means that maintaining similar conditions of slope and speed, the vehicle would have a range of 60 km if we have a full energy available of 10,800 Wh (150 Ah at 72 V). On the contrary, in favorable conditions (descents), even with higher speeds, the autonomy would be 267 km with the regeneration possible on the steepest descents.

2.6.3 Autonomy tests

Other tests were carried out to measure the autonomy on the road, to compare with the tests carried out on the roller (laboratory). Journeys were made in a section of approximately 20 km flat, maintaining a constant speed of 40 km / h and taking the vehicle from full battery charge (82 Vdc) to a total discharge of 62 Vdc, reaching 12 journeys. This represents an autonomy of 240 km under standard conditions (constant speed and flat terrain), very similar to the autonomy achieved in the laboratory. Figure 13 shows the power demanded; the transient peaks represent the power required at the start of the test where acceleration occurs. The total energy measured (area under the Power-time curve) was 11 kWh, as previously measured and estimated. This test defines a relative consumption of 46 Wh/km.

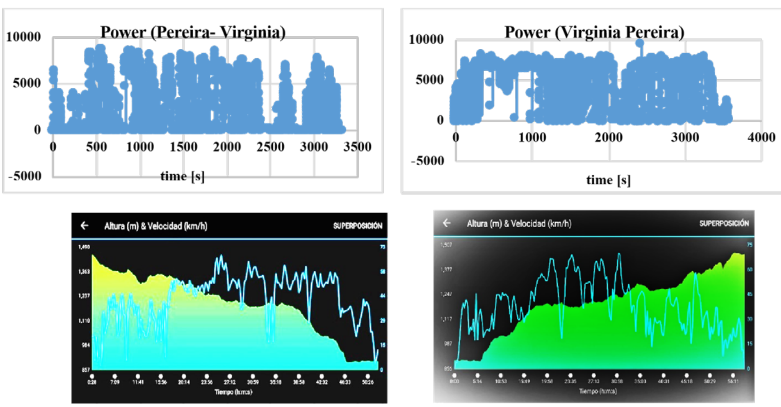
Figure 13. *Power measurement over a 240 km route under favorable conditions (constant speed and flat terrain)*



2.6.4 Long-distance tests

Longer journeys were also made between cities. The lack of charging stations on the road, force to limit the routes of the tests. With total passengers it traveled between the cities of Pereira and Virginia with a total distance of 100 km. Figure 15 shows the behavior of the power demanded by the engine, vehicle speed and travel altimetry.

Figure 14. *Power measurement over 240 km in favorable conditions (Constant speed and flat terrain)*



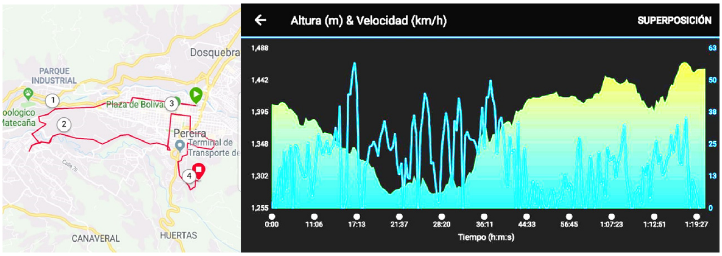
The energy consumption (area under the curve Power vs time of figure 15) in descent was 4085 Wh with an average consumption of 82 Wh / km, while in ascent it was 7932 Wh / km with an average consumption of 160 Wh / km . It is notable that in both routes the maximum power (8 kW) was demanded with greater constancy in the ascent. The average slope of this route (according to the altimetry profile) is 2%. The speed curves over time allow the estimation of accelerations, reaching in this case up to 0.8 m / s2 (example: increase from 20 to 30 km / h in 10 s). With this acceleration and the recorded slope, the model of the proposed traction dynamics (equation 1) is validated in a very successful way. It has been proven both in the traction model and experimentally that acceleration is the factor that most affects the power demanded.

Tests were also carried out on trips to more distant cities, with a certain recharge in the destination city, necessary for the return. Steep slopes were also made to observe the behavior and temperature of the engine reached.

2.6.5 Urban tests

In order to evaluate in a more real way the performance of the vehicle in conditions of greater use, as it is within the urban area, tours of the city of Pereira were made for 7 hours (from 12 to 7 pm), facing conditions associated with stops and starts continuous (typical of current traffic in a main city). Figure 15 presents the profiles of the route, altimetry and speeds reached.

Figure 15. *Route profile, altimetry and speed, urban area*



(a) Profile of the route (downtown area and periphery)

(b) Altimetry (green) and speed profile (blue) during a section of the route

The average slope recorded was 5%, with variations between 1270 and 1450 m.a.s.l. Distance recorded throughout the entire route was 108.5 km with an average speed of 16 km/h (considering all the stopping times). The total power consumption was 4230 Wh, corresponding to less than half the battery's full charge (10800 Wh). It is notable that speeds are maximum (50 km/h) in areas with negative slopes and with little traffic (outskirts of the city). In the routes of the downtown area logically the speeds are minimum with many continuous stops, being increased in the peak hours. In this scenario, the engine, despite having continuous accelerations, works with less demand on power. The power and torque curve of an electric motor shows that at low revs it can deliver maximum torque with low power demands. This was reflected in this type of route, where the engine temperature increased very slightly unlike the increase on the road. With the measured energy demand, a total journey of 14 hours through the city can be projected with a full battery charge, as long as the driving regime is regulated at low accelerations.

3. Results and discussion

Table 2 summarizes some of the tests carried out on the road, routes with different conditions of slope and speed.

Table 2. *Tests of different routes*

Tests of different routes

Route	Distance km	Average slope	Consumption energy (Wh)	Aver. Veloc. (km/h)	Time test (min)	Wh/km	Projected autonomy (km)
UTP -> Condina	9,89	+ 5,12 %	1858,2	27,6	21,3	188	58,5
Condina -> UTP	9,81	- 5,12 %	403,3	32,8	17,5	41,11	267
UTP->La Virginia	49,49	- 2 %	4085	38	52,57	82	132
La Virginia -> UTP	49,49	+ 2 %	7932	33,6	59,57	160	68
UTP->Santa Rosa	14,46	+ 10 %	2553.1	18	52,57	176,6	62,3
Santa Rosa -> UTP	14,45	- 10 %	897,16	28	32	62,08	177,2
UTP -> La Paila	87,37	- 1 %	7135	50,1	104	81,66	134,7
La Paila -> UTP	80,74	+ 1 %	9192	46	105	113,8	96,7
Recorrido Pereira	108,5	+/- 5 %	4230	16	420	134	277

According to the tests carried out (table 2), autonomy depends on multiple factors, as predicted by the traction model (equation 1) for some parameters. Variables such as grade, acceleration, speed, road conditions, vehicle weight (passengers), ambient temperature, travel (run time), stops and starts, and driving mode have some influence on autonomy (or average consumption Wh / km). Interestingly, the widest autonomy was found in the city, where there are more stops and starts, with a relatively low average speed. This operation at low revolutions makes the motor work in areas of high torque and low power (figure 12), making the energy level consumed relatively low over time. On the road, the level of power demanded is maximum since the speed reached is high and greater accelerations are required (in passing vehicles for example). In constant high power curves and a warm environment (such as Virginia for example), it causes the temperature of the battery to increase, reducing its efficiency, reaching consumptions of 160 Wh / km. Likewise, high slopes (10%) demand high consumption (177 Wh / km), projecting a range of only 62 km. Even for high demands, the motor's thermal release fins keep it at suitable temperature levels.

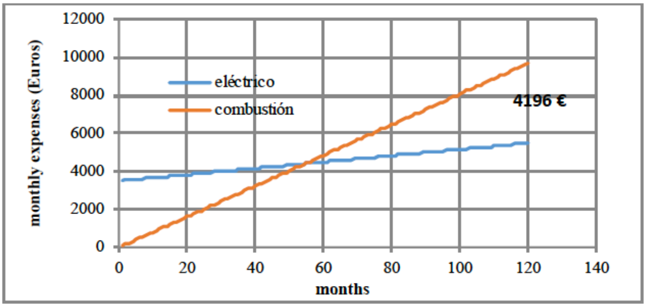
Figure 16 presents thermographic images of the engine, after the test on a steep road, registering a maximum value of 48.9 oC.

Figure 16. *Maximum temperature in high demand test (road with 10% gradient)*

A basic analysis of return on investment has been carried out considering not only initial investment, but also maintenance expenses and necessary mobility costs (monthly). This analysis includes the conversion price which includes the cost of the electrical kit and labor in the conversion. The maintenance required for an electric vehicle is zero or almost zero, without requiring periodic visits to the dealer. In terms of maintenance, some costs associated with a combustion vehicle are: oil change every 5000 km, gearbox and transmission oil change every 50,000 km, synchronization costs that must be done every 12,000 km. In addition to this, it requires a technical-mechanical inspection certificate at a cost of € 50, while an electrician does not require certification and only demands a revision of lights and peripherals (€ 6). Figure 18 presents the comparative costs between a combustion vehicle (before transformation) and an electric vehicle (transformed). It is also worth mentioning that there is a slight return on the sale of spare parts derived from the disassembly of the combustion system. Consumptions are taken under similar standard conditions.

The comparative analysis is carried out per month, assuming a journey of 1000 km (which corresponds to an average standard annual journey of 12000 km). The maintenance costs required for a combustion vehicle (deferred monthly) have been involved. Tax and soat (required) costs are considered equal. Figure 17 shows the respective graph highlighting the crossover point of the behavior of the expenses of each vehicle option.

Figure 17. *Projection of monthly expenses (accumulated) considering investment for transformation*



The crossover point shows that the return on investment is in month 55 (4 years, 7 months) if the monetary factor is analyzed exclusively, however, it can highlight the fact of the profit from future savings, which amounts to 4196 € in year 10 (120 months). Increases in changing costs over time (such as gasoline or electricity) due to inflation, which could reduce the return time, have not been considered. In addition, electric vehicles enjoy exemption from restrictions for their mobility in the main cities of the country. Expenses generated by this restriction in combustion vehicles are not considered in this analysis.

4. Conclusions.

Experimental tests have shown that the power depends on the established load conditions, validating the proposed model (equation 1), figure 4. On flat terrain (slope 0) the vehicle (with all its occupants) has reached speeds of 80 km / h with a full power of 8 kW (constant speed). The battery has been discharged under different charging conditions showing different autonomy values. In the most favorable conditions, the vehicle has reached autonomy values of 240 km (in the laboratory) and close to 200 km on the road (10,800 Wh, 82 to 62 Vdc). However, in urban areas (even with traffic) it could exceed these values, since the engine works mainly in low-rev areas, with high torques but at low power.

Tests carried out on the combustion vehicle (before conversion) showed that the fuel consumption was 6.54 L per 100 km, showing high levels of contamination (CO: 1.808 g / km, THC + NOx: 0.652 g / km), exceeding the admissible international limits, generating a high impact on the carbon footprint.

Comparative mass analysis showed that the transformation of a combustion vehicle to electric can have a reduction of the total mass of almost 30% and therefore the load demanded.

The economic factor represents an important reason to carry out this type of conversions, mainly in the Latin American context. In Colombia, for example, the total cost of the electrical system oscillates around € 3,500 (15,000,000 COP approx.). A new electric vehicle costs about 100,000,000 COP (23,800 €), excessive costs, with transformation being a feasible option.

Economic analyzes have shown that the return on investment can be achieved in 4.5 years, considering the savings due to the expenses derived from fuel and maintenance required in combustion vehicles. In 10 years, savings of $ 17,600,000 (€ 4,200) can be achieved, which can be used to purchase a new battery and a new conversion or installation of a charging station.

Regarding the mitigation of greenhouse gases, with an electric vehicle, 21.7 kg of CO, 7.8 kg of NOx - THC and 1.8 Tons of CO2 are no longer sent into the atmosphere annually (taking emission of 150 g CO2 / km and 12,000 km per year).

References

Asimakopoulos, A.P. et al. (2010). Experience derived from the conversion of a conventional car to a hybrid electric vehicle -analysis of the powertrain. *IEEE.*

Clement-Nyns, K., Haesen, E. & Driesen, J. (2009). The Impact of Charging Plug-In Hybrid Electric Vehicles on a Residential Distribution Grid. *IEEE transaction on Power system, 25*(1). 371-380.

Delphi, T. M. (2017-2018). *"Worldwide Emissions Standards - Passenger Cars and Light Duty"*.

Diario Correo. (2018, marzo 19). "La contaminación sonora y los serios daños que provoca en tu salud". *Diario Correo.*

Duque, D. y Rocano, J. (2018). *"Determinación de la autonomía del vehículo eléctrico mediante ciclos controlados"*. Trabajo de titulación del Título de Ingeniero Mecánico Automotriz, Universidad Politécnica Salesiana sede Matriz Cuenca.

Gillespie, T.D. (1992). Fundamentals of vehicle Dynamics. *Society of Automotive Engineers*.

González, S. et al . (2010). "Proyecto de conversión de un automóvil de combustión interna en eléctrico", ULPGC - Universidad de Las Palmas de Gran Canaria.

Jazar, R.N. (2016). *Vehicle Dynamics, Theory and Application.* Boston: Springer

Landrigan et al. (2017). The Lancet Commission on pollution and health. *The Lancet*, 391, 462-512.

Peças, J.A., Soares, F.J. & Rocha, P. (2011).Integration of Electric Vehicles in the Electric Power System. *Proceeding of the IEEE, 99*(1), 168-183

Ramírez, D. y Domínguez, E.A. (2011). El ruido vehicular urbano: problemática agobiante de los países en vías de desarrollo. *Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales, 35*(137), 509-530.

Rodríguez et al. (2015). *"*Estudios sobre el desempeño de Vehículos Eléctricos Dependiendo de la Arquitectura de su Sistema de Tracción*"*, Thesis, Facultad de Ingeniería Eléctrica y Electrónica, Universidad Pontificia Bolivariana, Medellín, Antioquia, Colombia.

UPME (2019). "Retos de la eficiencia energética en la transición energética colombiana". 9º Seminario de Eficiencia Energética. Concurso de eficiencia energética. Bogotá, abril 25 y 26.

Vidal, J. (2012). Air pollution rising at an 'alarming rate' in world's cities*. The guardian magazine.*